DANISH TECHNOLOGICAL INSTITUTE

ID No.: THERM 06 Temperature

Report of proficiency test (Interlaboratory comparison)

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Report of proficiency test

Item:

Digital thermometer with two Pt100 sensors

Reference laboratory:

Danish Technological Institute
Temperature Laboratory, DANAK reg. No. 200
Kongsvang Allé 29
DK-8000 Aarhus C
Denmark

Coordinator:

Danish Technological Institute
Installation and Calibration
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DK-8000 Aarhus C
Denmark

Jan Nielsen, Team Manager

Conditions: The proficiency test has been carried out in compliance with the guidelines laid down for the Laboratory by DANAK (The Danish Accreditation Fund) see: www.DANAK.dk) and in compliance with the Danish Technological Institute's General Terms and Conditions regarding Commissioned Work: http://www.dti.dk/who-are-we/general-terms-and-conditions/23888,2.

Division/Centre: Energy and Climate
Installation and Calibration

Signature:

Jan Nielsen
Team Manager, Metrology

Contents

1. Introduction

This report summarises the results of the THERM 06 intercomparison. The intercomparison includes seven measuring points in the range -40 °C to 230 °C for two sensors: 4 mm and 9 mm Pt100. The objective of this interlaboratory comparison within the metrological field "contact thermometry" is to compare the measurement capabilities of all the participating laboratories. The intercomparison was mainly aimed at laboratories using equipment such as dry block calibrators for calibration, but several of the participants chose to calibrate the thermometers by comparison in liquid baths.

The intercomparison was carried out in three loops and had in total 33 participants from 13 different countries. The audit devices were calibrated by the pilot laboratory at Danish Technological Institute (DTI) before, between and after the circulation of the devices.

All measurements reported in this report were carried out from June 2016 to May 2017.

The intercomparison was carried out in accordance with DS/EN ISO/IEC 17043:2010.

1.1. Time schedule

The intercomparison was carried out in the period from June 2016 to May 2017. Some delay was encountered due to several incidents: In loop 1, the 9 mm sensor was damaged, sent to the manufacturer for repair and recalibrated after the repair. This delayed the loop for more than one month. In loop 3, significant delay occurred, as three of the participants did not keep the time schedule, which resulted in other delays due to public holidays in the participating countries. It was possible to catch up with some of the delay by moving participants between loops.

2. Conclusion

The intercomparison THERM 06 is finalized. The intercomparison had 33 participants from 13 different countries. The measurements reported were carried out in the period from June 2016 to May 2017. One transfer standard, the 9 mm sensor in loop 1 was damaged and repaired, but the recalibration showed good reproducibility. Both 4 mm sensors used as transfer standard in loop 1 and 2 was damaged (bent) somewhere during the circulation. Unfortunately this mechanical damage resulted in non-reproducible results at 150 °C and 230 °C for the loop 1 sensor and at 230 °C for the loop 2 sensor. Consequently E_n-values have not been evaluated at these particular measurement points. The stability of the other transfer standards during the loops was acceptable. The analysis shows that 2 out of 33 participants has $|En| > 1$. The rest of the participants' results were satisfactory. One participant (named Lab 23 in the report) never sent any results to the coordinator.

Some of the participants chose to calibrate the sensors by comparison in a liquid bath and a few of them stated uncertainties close to the uncertainty of the reference value. These participants are encouraged to make a further analysis of the results and of their uncertainty budgets.

3. E_n-values

The evaluation of the performance is made using the calculated normalised error (see table 1):

$$E_n = \frac{t_{lab} - t_{ref}}{\sqrt{U_{lab}^2 + U_{ref}^2}} \quad (1)$$

where

E_n = Normalised error

t_{lab} - t_{ref} = Deviation between the value reported by the participating laboratory and the reference value (see also 5.1)

U_{lab} = Expanded uncertainty stated by the participating laboratory

U_{ref} = Expanded uncertainty of t_{ref} found by DTI

A result is considered satisfactory when the numerical value of $|E_n| \leq 1$.

3.1. E_n-values – 4 mm sensor

Lab code	Nominal temperature						
	-40 °C	-20 °C	-10 °C	0 °C	75 °C	150 °C	230 °C
1			-0.2	-0.2	-0.1	NE	NE
2					0.0	NE	NE
3		-0.2	0.0	0.1	0.2	0.4	
4	1.0	**1.3**	0.8	0.7	0.4	0.4	0.1
5	-0.2	-0.2	-0.2	-0.3	-0.3	-0.6	-0.5
6		0.2	-0.7	-0.2	0.1	-0.2	0.3
7		0.0	0.0	0.0	0.0		
8	0.1	0.2	0.1	0.0	-0.4	-0.3	
9	0.6	0.4	0.3	0.3	0.5	0.6	0.4
10	0.0	0.1	0.1	0.2	0.1	0.0	0.1
11	-0.5	-0.4	-0.5	-0.5	-0.7	-0.9	NE
12	0.2	0.0	0.0	0.0	0.0	0.5	NE
13	0.5	0.7	0.5	0.5	0.7	NE	NE
14	0.3	0.4	0.4	0.4	0.2	NE	NE
15		-0.5	0.3	0.5	0.6	NE	NE
16	0.1	0.1	0.1	0.1	0.2	NE	NE
17		0.0	0.0	0.0	0.0	-0.1	0.4
18		-0.1	-0.1	-0.1	0.0	0.0	0.0
19	0.1	0.2	0.1	0.3	0.4	0.4	0.5
20	0.1	0.1	-0.1	-0.2	-0.4	-0.3	0.1

Lab code	Nominal temperature						
	-40 °C	-20 °C	-10 °C	0 °C	75 °C	150 °C	230 °C
21		-0.2	-0.1	0.0	0.3	0.0	NE
22		-0.5		0.1	0.2	NE	NE
23						NE	NE
24	-0.2	0.3	0.3	0.1	-0.5	NE	NE
25	-0.3	0.0	0.0	0.1	0.1	NE	NE
26	-0.2	-0.1	0.0	0.0	0.7	0.4	0.1
27	0.0	0.2	0.1	0.0	-0.4	-0.2	
28	0.3	0.2	0.3	0.2	0.9	0.3	0.3
29	-0.2	-0.1	-0.1	-0.1	0.1	0.0	-0.2
30	0.2	0.1	-0.4	-0.3	-0.1	0.0	0.0
31		0.0	0.0	0.0	-0.1	0.1	
32	0.9	-0.4	-0.7	0.0	-0.2	-0.3	NE
33	0.4	0.6	0.5	0.6	0.7	NE	NE

Table 1: Normalised errors, E_n, for all participants calibrating the 4 mm sensor, when marked "NE" the E_n-value is not evaluated because of non-reproducible results caused by mechanical damage of the sensor.

3.2. E_n-values – 9 mm sensor

Lab code	Nominal temperature						
	-40 °C	-20 °C	-10 °C	0 °C	75 °C	150 °C	230 °C
1			0.1	0.0	0.1	0.1	0.3
2					-0.1	0.0	0.1
3		-0.4	-0.4	-0.4	-0.3	-0.1	
4	0.4	0.4	0.3	0.2	-0.3	-0.3	-0.8
5	-0.1	0.0	0.0	-0.3	-0.2	-0.3	-0.3
6		-0.3	0.0	0.0	-0.4	-0.5	-0.1
7		0.0	0.0	-0.1	0.0		
8	0.5	1.0	0.8	0.4	0.4	0.3	
9	-0.1	-0.1	-0.1	-0.2	-0.2	0.4	0.7
10	0.0	0.1	0.1	0.2	0.1	0.0	-0.1
11	-0.4	-0.2	-0.3	-0.3	-0.4	-0.6	0.1
12	0.2	0.0	0.0	-0.1	0.0	0.1	0.1
13	0.0	0.2	0.3	0.4	0.7	0.8	
14	0.2	0.3	0.3	0.3	0.2	0.1	1.0
15		0.6	0.9	0.9	0.2	-0.6	
16	0.2	0.2	0.2	0.2	0.5	0.5	0.2
17		0.0	0.0	0.0	-0.1	-0.1	0.1
18		-0.2	-0.2	-0.2	0.0	0.0	0.0
19	-0.2	0.0	0.0	0.1	0.1	0.1	0.2
20	0.1	0.1	0.0	-0.1	-0.3	0.0	-0.2

Lab code	Nominal temperature						
	-40 °C	-20 °C	-10 °C	0 °C	75 °C	150 °C	230 °C
21		0.5	0.4	0.0	-0.1	-0.1	
22		-0.5		0.0	0.1	0.4	0.2
23							
24	-0.4	0.1	0.1	-0.5	-0.2	-0.1	0.4
25	0.0	0.0	0.0	0.0	0.1	0.1	0.2
26	0.0	0.0	-0.1	-0.1	-0.3	-0.7	-0.9
27	0.0	-0.1	-0.2	-0.4	-0.8	**-1.4**	
28	0.6	-0.1	-0.1	0.0	0.1	1.0	
29	-0.2	-0.1	0.0	0.0	0.2	0.1	0.0
30	0.0	0.2	0.2	-0.5	-0.1	0.0	0.0
31		0.0	0.0	0.1	0.0	0.0	
32	-0.2	0.1	-0.3	-0.2	-0.4	-0.3	-0.2
33	0.1	0.1	0.2	0.0	0.4	0.1	

Table 2: Normalised errors, E_n, for all participants calibrating the 9 mm sensor.

4. Description of the item

The measuring devices are digital thermometers with two Pt100 sensors:

Instrument 1 (loop 1):

Manufacturer: Ametek
Type no.: DTI1000
Serial no.: 004568-01057
Range: -40 °C to 230 °C
Resolution: 0,001 °C
Power supply: 230 V/50 Hz
Ch 1 Sensor: SN 637287-04 (4 mm)
Ch 2 Sensor: SN 642111-03 (9 mm)

Instrument 2 (loop 2):

Manufacturer: Ametek
Type no.: DTI1000
Serial no.: 522081-01646
Range: -40 °C to 230 °C
Resolution: 0.001 °C
Power supply: 230 V/50 Hz
Ch 1 Sensor: SN 637287-07 (4 mm)
Ch 2 Sensor: SN 642111-02 (9 mm)

Instrument 3 (loop 3):

Manufacturer:	Fluke
Type no.:	1586 A & 1586-2588
Serial no.:	25740003/26360027
Range:	-40 °C to 230 °C
Resolution:	0.001 °C
Power supply:	230 V/50 Hz - grounded
Ch 201 Sensor:	SN 642111-01 (9 mm)
Ch 202 Sensor:	SN 637287-10 (4 mm)

5. Results

5.1. Calculation of reference values

The audit devices were calibrated by DTI by comparison to fixed point calibrated Standard Platinum Resistance Thermometer (SPRT) in liquid baths, and in accordance with the calibration procedures, accredited by DANAK reg. No. 200 (www.danak.dk). For loop 1 an extra calibration was performed after the 9 mm sensor was repaired after being damaged.

Based on the calibration a least square fit was made over the range to determine the coefficients A_i in the following equation:

$$t_{ref} = \sum_{i=0}^{4} A_i \cdot t_{\mathrm{ind},i}^{i} \qquad (2)$$

where t_{ind} is the indication of the thermometer.

The reference values are calculated as the mean value of two successive calibrations performed by DTI.

A "unique" reference value is then determined from equation (2), for each particular measurement reported by the participant. The coefficients used for this calculations are given in Appendix 1.

5.2. Evaluation of uncertainty

The reported expanded uncertainty of the mean reference values is stated as the standard uncertainty of measurement multiplied by the coverage factor k = 2, providing a level of confidence of approximately 95 %.

The expanded uncertainty as reported in appendix 2 is calculated according to JCGM 100:2008 (see [1]).

The uncertainty includes contributions from the reference set-ups used, short-term contributions from the device under calibration, a contribution from repeatability and a contribution from the drift over time. The uncertainty contributing from the drift is calculated

from the minimum and maximum measured error, assuming a rectangular distribution (as 4.3.7 in [1]).

5.3. Traceability

The performed calibrations are covered by the DANAK accreditation and the multilateral agreements with EA and ILAC for calibration. This ensures that measurements are traceable to the international system of units, SI.

5.4. Results of the participating laboratories

The laboratories having anomalous results, i.e. if the results did not comply with $|En| \leq 1$ or when we detected obvious errors in the data, were asked to recheck their data and either confirm the data or send corrected values. Laboratory 27 sent corrected data sheets.

The results of the laboratories are shown in the appendices. All laboratories are anonymized in the report.

Some of the participants chose to calibrate the sensors by comparison in a liquid bath (see table 3) and a few of them stated uncertainties close to the uncertainty of the reference value. These participants are encouraged to make a further analysis of the results and of their uncertainty budgets.

Lab code	Method
1, 2, 3, 4, 7, 12, 13, 14, 15, 16, 18, 21, 22, 24, 28, 30	Dry-block calibrator
5, 6, 8, 9, 10, 11, 17, 19, 20, 25, 26, 29, 31, 32, 33	Comparison in liquid bath
27	Comparison in climatic chamber

Table 3: Method used by the participating laboratory

6. References

[1] Evaluation of measurement data – Guide to the expression of uncertainty in measurement, JCGM 100:2008 (www.bipm.org)

Appendix 1: Reference functions

In this appendix the coefficients of the calibration equations as determined by DTI (see 5.1), is given. The reference values are calculated from the mean value of the calibrations performed by DTI in a given period of time:

	2016.06.02 to 2016.10.21	2016.10.21 to 2016.12.21	2016.12.21 to 2017.05.23
A_0	-9.99E-02	-1.21E-01	-1.40E-01
A_1	9.99E-01	9.99E-01	9.99E-01
A_2	3.69E-05	-1.16E-05	-8.67E-06
A_3	3.28E-07	-6.00E-08	-1.00E-07
A_4	-1.04E-08	4.21E-09	3.55E-09

Table 4: Coefficients used for calculating t_{ref} for the Loop 1 – 4 mm sensor.

	2016.06.02 to 2016.10.21	2016.10.21 to 2016.12.21	2016.12.21 to 2017.05.23
A_0	1.15E-03	-2.76E-03	-6.24E-03
A_1	9.99E-01	9.99E-01	9.99E-01
A_2	5.54E-06	4.95E-06	5.27E-06
A_3	9.76E-09	1.04E-08	4.43E-09
A_4	-7.34E-11	-5.91E-11	-3.96E-11

Table 5: Coefficients used for calculating t_{ref} for the Loop 1 – 9 mm sensor.

	2016.06.02 to 2016.10.21	2016.10.21 to 2017.05.23
A_0	4.49E-02	2.00E-02
A_1	9.99E-01	1.00E+00
A_2	4.00E-06	5.18E-06
A_3	5.91E-08	-9.76E-09
A_4	-3.67E-10	-1.81E-12

Table 6: Coefficients used for calculating t_{ref} for the Loop 2 – 4 mm sensor.

	2016.06.02 to 2016.10.21	2016.10.21 to 2017.05.23
A_0	-1.76E-03	-1.78E-02
A_1	1.00E+00	1.00E+00
A_2	6.82E-06	8.37E-06
A_3	-8.54E-09	-1.66E-08
A_4	-1.21E-11	1.37E-12

Table 7: Coefficients used for calculating t_{ref} for the Loop 2 – 9 mm sensor.

	2016.06.02 to 2016.10.21	2016.10.21 to 2017.05.23
A_0	4.40E-02	2.43E-02
A_1	1.00E+00	1.00E+00
A_2	2.85E-06	2.88E-06
A_3	7.73E-09	7.50E-09
A_4	-4.30E-11	-4.44E-11

Table 8: Coefficients used for calculating t_{ref} for the Loop 3 – 4 mm sensor.

	2016.06.02 to 2016.10.21	2016.10.21 to 2017.05.23
A_0	-2.17E-02	-2.68E-02
A_1	9.99E-01	9.99E-01
A_2	9.27E-06	6.52E-06
A_3	-3.35E-08	-7.14E-09
A_4	5.48E-11	-1.22E-11

Table 9: Coefficients used for calculating t_{ref} for the Loop 3 – 9 mm sensor.

Appendix 2: Uncertainty of reference values

In this appendix, the uncertainty of the reference values U_{ref}, is given in the tables below.

Nominal temperature	2016.06.02 to 2016.10.21	2016.10.21 to 2016.12.21	2016.12.21 to 2017.05.23
-40 °C	0.014 K	0.016 K	0.015 K
-20 °C	0.018 K	0.017 K	0.014 K
-10 °C	0.017 K	0.012 K	0.017 K
0 °C	0.015 K	0.010 K	0.013 K
75 °C	0.019 K	0.015 K	0.017 K
150 °C	NE	NE	NE
230 °C	NE	NE	NE

Table 10: U_{ref} for the Loop 1 – 4 mm sensor. When marked "NE" the uncertainty is not evaluated because of non-reproducible results caused by mechanical damage of the sensor.

Nominal temperature	2016.06.02 to 2016.10.21	2016.10.21 to 2016.12.21	2016.12.21 to 2017.05.23
-40 °C	0.031 K	0.032 K	0.032 K
-20 °C	0.025 K	0.032 K	0.032 K
-10 °C	0.025 K	0.032 K	0.032 K
0 °C	0.017 K	0.019 K	0.019 K
75 °C	0.019 K	0.021 K	0.020 K
150 °C	0.021 K	0.021 K	0.021 K
230 °C	0.027 K	0.023 K	0.023 K

Table 11: U_{ref} for the Loop 1 – 9 mm sensor.

Nominal temperature	2016.06.02 to 2016.10.21	2016.10.21 to 2017.05.23
-40 °C	0.016 K	0.025 K
-20 °C	0.021 K	0.021 K
-10 °C	0.022 K	0.020 K
0 °C	0.021 K	0.019 K
75 °C	0.023 K	0.023 K
150 °C	0.027 K	0.025 K
230 °C	NE	0.031 K

Table 12: U_{ref} for the Loop 2 – 4 mm sensor. When marked "NE" the uncertainty is not evaluated because of non-reproducible results caused by mechanical damage of the sensor.

Nominal temperature	2016.06.02 to 2016.10.21	2016.10.21 to 2017.05.23
-40 °C	0.038 K	0.039 K
-20 °C	0.034 K	0.033 K
-10 °C	0.034 K	0.033 K
0 °C	0.030 K	0.028 K
75 °C	0.030 K	0.029 K
150 °C	0.029 K	0.031 K
230 °C	0.032 K	0.030 K

Table 13: U_{ref} for the Loop 2 – 9 mm sensor.

Nominal temperature	2016.06.02 to 2016.10.21	2016.10.21 to 2017.05.23
-40 °C	0.015 K	0.013 K
-20 °C	0.014 K	0.014 K
-10 °C	0.013 K	0.015 K
0 °C	0.011 K	0.014 K
75 °C	0.013 K	0.018 K
150 °C	0.019 K	0.022 K
230 °C	0.022 K	0.028 K

Table 14: U_{ref} for the Loop 3 – 4 mm sensor.

Nominal temperature	2016.06.02 to 2016.10.21	2016.10.21 to 2017.05.23
-40 °C	0.033 K	0.029 K
-20 °C	0.031 K	0.029 K
-10 °C	0.030 K	0.029 K
0 °C	0.017 K	0.015 K
75 °C	0.021 K	0.016 K
150 °C	0.021 K	0.016 K
230 °C	0.024 K	0.018 K

Table 15: U_{ref} for the Loop 3 – 9 mm sensor.

Appendix 3: Results - Tables

In this appendix, the results of the deviation of the participants' result from the reference value are depicted as well as the errors and uncertainty reported by the participants.

Lab code	Nominal temperature						
	-40 °C	-20 °C	-10 °C	0 °C	75 °C	150 °C	230 °C
1			-0.011	-0.011	-0.005	NE	NE
2					-0.01	NE	NE
3		-0.008	0.000	0.006	0.014	0.028	
4	0.031	0.037	0.023	0.018	0.018	0.020	0.009
5	-0.008	-0.005	-0.006	-0.006	-0.011	-0.018	-0.020
6		0.005	-0.016	-0.004	0.003	-0.006	0.010
7		0.01	0.00	-0.01	-0.01		
8	0.002	0.006	0.003	0.001	-0.011	-0.010	
9	0.013	0.008	0.005	0.006	0.011	0.015	0.012
10	-0.001	0.005	0.004	0.005	0.004	0.002	0.005
11	-0.019	-0.016	-0.018	-0.019	-0.027	-0.037	NE
12	0.11	0.01	-0.01	-0.02	-0.01	0.29	NE
13	0.014	0.018	0.014	0.012	0.020	NE	NE
14	0.016	0.020	0.019	0.020	0.008	NE	NE
15		-0.11	0.06	0.11	0.14	NE	NE
16	0.005	0.005	0.009	0.011	0.013	NE	NE
17		0.001	0.000	-0.003	-0.001	-0.006	0.07
18		-0.02	-0.02	-0.02	-0.01	-0.01	0.00
19	0.001	0.006	0.003	0.006	0.009	0.010	0.015
20	0.006	0.003	-0.003	-0.007	-0.012	-0.010	0.005
21		-0.02	-0.01	0.00	0.03	0.02	NE
22		-0.08		0.02	0.04	NE	NE
23						NE	NE
24	-0.06	0.09	0.07	0.02	-0.12	NE	NE
25	-0.04	0.00	0.00	0.01	0.01	NE	NE
26	-0.02	-0.01	0.00	0.00	0.07	0.04	0.03
27	0.01	0.03	0.02	0.00	-0.06	-0.03	
28	0.021	0.018	0.021	0.015	0.070	0.027	0.06
29	-0.022	-0.012	-0.010	-0.009	0.009	-0.002	-0.018
30	0.015	0.006	-0.040	-0.007	-0.006	-0.003	0.004
31		0.00	0.00	0.00	-0.01	0.01	
32	0.077	-0.036	-0.060	-0.001	-0.007	-0.019	NE
33	0.013	0.015	0.015	0.016	0.021	NE	NE

Table 16: Deviation from the reference value for the 4 mm sensor in °C. When marked "NE" the deviation is not evaluated because of non-reproducible results caused by mechanical damage of the sensor.

Lab code	Nominal temperature						
	-40 °C	-20 °C	-10 °C	0 °C	75 °C	150 °C	230 °C
1			0.008	0.002	0.008	0.006	0.022
2					-0.01	0.01	0.03
3		-0.021	-0.021	-0.019	-0.018	-0.005	
4	0.024	0.016	0.012	0.009	-0.015	-0.016	-0.052
5	-0.004	0.001	0.000	-0.008	-0.008	-0.011	-0.014
6		-0.011	-0.002	0.001	-0.012	-0.015	-0.003
7		0.00	0.00	-0.01	0.00		
8	0.019	0.036	0.030	0.011	0.011	0.009	
9	-0.002	-0.005	-0.005	-0.005	-0.006	0.013	0.022
10	0.000	0.008	0.007	0.009	0.005	0.002	-0.005
11	-0.018	-0.011	-0.012	-0.013	-0.016	-0.023	0.003
12	0.11	0.01	-0.02	-0.03	0.02	0.05	0.06
13	0.001	0.011	0.012	0.015	0.029	0.034	
14	0.012	0.015	0.016	0.015	0.007	0.003	0.049
15		0.15	0.22	0.21	0.04	-0.14	
16	0.013	0.018	0.020	0.020	0.038	0.041	0.06
17		-0.001	0.000	0.003	-0.005	-0.01	0.01
18		-0.02	-0.02	-0.02	-0.02	-0.03	-0.03
19	-0.007	0.002	0.001	0.003	0.003	0.002	0.006
20	0.006	0.003	-0.001	-0.003	-0.011	0.001	-0.011
21		0.05	0.04	0.00	-0.01	-0.05	
22		-0.09		0.00	0.02	0.15	0.09
23							
24	-0.13	0.02	0.02	-0.08	-0.05	-0.02	0.08
25	0.00	0.00	0.00	0.00	0.01	0.01	0.02
26	0.00	0.00	-0.01	-0.01	-0.03	-0.15	-0.26
27	-0.01	-0.02	-0.03	-0.06	-0.12	-0.26	
28	0.043	-0.004	-0.006	-0.003	0.009	0.070	
29	-0.020	-0.007	-0.002	0.001	0.020	0.011	-0.002
30	0.003	0.020	0.024	-0.015	-0.01	0.00	0.00
31		0.00	0.00	0.01	0.00	0.00	
32	-0.015	0.008	-0.027	-0.007	-0.015	-0.015	-0.017
33	0.003	0.005	0.006	0.001	0.012	0.006	

Table 17: Deviation from the reference value for the 9 mm sensor in °C.

Lab code	Nominal temperature						
	-40 °C	-20 °C	-10 °C	0 °C	75 °C	150 °C	230 °C
1			0.098	0.111	0.160	0.179	0.299
2					0.21	0.22	0.25
3		-0.048	-0.051	-0.051	-0.055	-0.098	
4	-0.078	-0.068	-0.048	-0.038	-0.028	-0.055	-0.074
5	-0.039	-0.026	-0.019	-0.014	0.000	-0.016	-0.045
6		-0.058	-0.032	-0.040	-0.036	-0.048	-0.088
7		-0.04	-0.03	-0.02	0.00		
8	-0.047	-0.040	-0.032	-0.025	0.001	-0.018	
9	-0.076	-0.061	-0.053	-0.050	-0.043	-0.069	-0.091
10	-0.046	-0.036	-0.029	-0.025	-0.015	-0.036	-0.070
11	-0.049	-0.040	-0.032	-0.026	-0.015	-0.032	-0.111
12	-0.18	-0.07	-0.04	-0.02	-0.04	-0.35	-0.63
13	0.079	0.101	0.115	0.128	0.185	0.219	
14	0.055	0.077	0.089	0.101	0.172	0.232	0.289
15		0.18	0.03	-0.01	0.01	0.07	
16	0.045	0.065	0.078	0.089	0.142	0.163	0.22
17		-0.054	-0.048	-0.041	-0.032	-0.05	-0.15
18		-0.04	-0.03	-0.02	-0.02	-0.04	-0.08
19	-0.065	-0.059	-0.051	-0.050	-0.042	-0.064	-0.094
20	-0.053	-0.034	-0.022	-0.013	0.001	-0.024	-0.070
21		-0.04	-0.04	-0.04	-0.07	-0.09	0.05
22		0.20		0.12	0.17	0.06	0.11
23							
24	0.11	-0.02	0.02	0.08	0.28	0.18	0.17
25	0.13	0.12	0.13	0.13	0.19	0.22	0.24
26	-0.03	-0.02	-0.03	-0.02	-0.08	-0.08	-0.09
27	-0.054	-0.066	-0.047	-0.017	0.053	-0.003	
28	-0.067	-0.052	-0.050	-0.039	-0.080	-0.054	-0.11
29	-0.024	-0.022	-0.019	-0.015	-0.019	-0.025	-0.026
30	-0.078	-0.059	-0.008	-0.037	-0.027	-0.050	-0.082
31		-0.03	-0.03	-0.02	0.00	-0.04	
32	-0.145	-0.021	0.009	-0.044	-0.034	-0.051	-0.084
33	0.080	0.104	0.115	0.125	0.183	0.214	

Table 18: Errors reported by the participants for the 4 mm sensor in °C.

Lab code	Nominal temperature						
	-40 °C	-20 °C	-10 °C	0 °C	75 °C	150 °C	230 °C
1			0.065	0.065	0.065	0.065	0.084
2					0.19	0.23	0.27
3		0.042	0.042	0.042	0.052	0.062	
4	0.020	0.020	0.020	0.020	0.040	0.040	0.050
5	0.021	0.021	0.021	0.010	0.021	0.021	0.031
6		0.030	0.020	0.020	0.020	0.020	0.020
7		0.16	0.16	0.16	0.16		
8	0.020	0.020	0.020	0.020	0.020	0.020	
9	0.015	0.015	0.015	0.015	0.015	0.015	0.020
10	0.040	0.030	0.030	0.020	0.030	0.040	0.040
11	0.030	0.030	0.030	0.030	0.030	0.030	0.030
12	0.50	0.50	0.50	0.50	0.50	0.60	0.60
13	0.021	0.021	0.021	0.020	0.022	0.022	
14	0.044	0.044	0.044	0.044	0.044	0.044	0.044
15		0.23	0.23	0.23	0.23	0.23	
16	0.080	0.080	0.080	0.080	0.080	0.080	0.36
17		0.080	0.080	0.080	0.080	0.11	0.17
18		0.14	0.14	0.14	0.60	0.60	0.60
19	0.020	0.020	0.020	0.020	0.020	0.020	0.020
20	0.045	0.025	0.025	0.025	0.020	0.026	0.063
21		0.10	0.10	0.10	0.10	0.60	0.60
22		0.17		0.17	0.18	0.35	0.39
23							
24	0.33	0.26	0.22	0.16	0.26	0.28	0.20
25	0.10	0.11	0.11	0.10	0.10	0.10	0.10
26	0.10	0.10	0.10	0.10	0.10	0.10	0.20
27	0.021	0.021	0.021	0.010	0.021	0.021	0.031
28	0.080	0.080	0.080	0.080	0.080	0.080	0.20
29	0.093	0.093	0.093	0.093	0.093	0.093	0.093
30	0.096	0.096	0.096	0.025	0.096	0.096	0.096
31		0.10	0.10	0.10	0.10	0.10	
32	0.080	0.080	0.080	0.010	0.030	0.050	0.080
33	0.024	0.023	0.023	0.023	0.024	0.027	

Table 19: Uncertainty reported by the participants for the 4 mm sensor in °C.

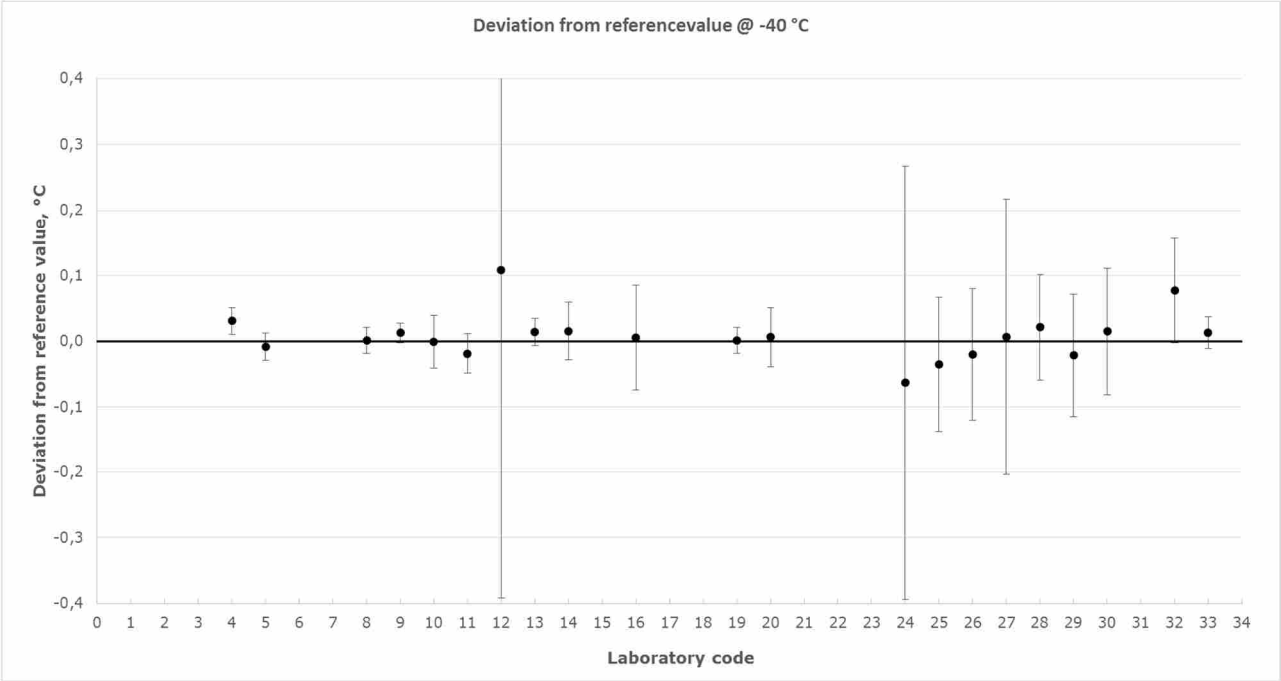
Lab code	Nominal temperature						
	-40 °C	-20 °C	-10 °C	0 °C	75 °C	150 °C	230 °C
1			-0.015	-0.003	-0.004	-0.050	-0.112
2					0.03	-0.04	-0.12
3		0.019	0.022	0.021	-0.011	-0.104	
4	-0.027	-0.004	0.003	0.008	0.003	-0.079	-0.143
5	0.002	0.011	0.016	0.026	-0.004	-0.083	-0.181
6		0.018	0.017	0.021	0.035	-0.005	-0.086
7		0.01	0.02	0.04	0.03		
8	-0.023	-0.022	-0.009	0.016	0.021	-0.022	
9	-0.015	0.012	0.020	0.027	0.029	-0.033	-0.112
10	-0.002	0.004	0.009	0.009	-0.017	-0.096	-0.190
11	0.006	0.009	0.013	0.015	-0.013	-0.086	-0.213
12	-0.12	-0.01	0.02	0.03	-0.05	-0.16	-0.27
13	-0.024	-0.017	-0.012	-0.009	-0.014	-0.062	
14	-0.037	-0.025	-0.019	-0.012	0.004	-0.039	-0.150
15		-0.16	-0.23	-0.21	-0.03	0.10	
16	-0.043	-0.032	-0.027	-0.021	-0.034	-0.086	-0.15
17		0.008	0.015	0.019	0.028	-0.01	-0.10
18		0.03	0.04	0.04	0.04	0.01	-0.06
19	-0.010	0.005	0.014	0.019	0.020	-0.022	-0.096
20	-0.009	0.008	0.016	0.021	-0.001	-0.095	-0.184
21		-0.05	-0.04	0.00	-0.02	-0.06	
22		0.08		0.00	-0.01	-0.18	-0.19
23							
24	0.10	-0.03	-0.03	0.08	0.05	-0.03	-0.17
25	-0.02	-0.01	0.00	0.01	0.01	-0.04	-0.11
26	0.00	0.01	0.03	0.02	0.02	0.05	0.07
27	0.00	0.03	0.05	0.08	0.11	0.17	
28	-0.048	0.018	0.027	0.030	0.023	-0.083	
29	0.015	0.021	0.023	0.026	0.012	-0.024	-0.077
30	-0.020	-0.013	-0.009	0.037	0.03	-0.02	-0.09
31		0.01	0.01	0.01	-0.01	-0.10	
32	0.003	-0.010	0.028	0.009	-0.014	-0.094	-0.193
33	-0.025	-0.011	-0.006	0.006	0.003	-0.035	

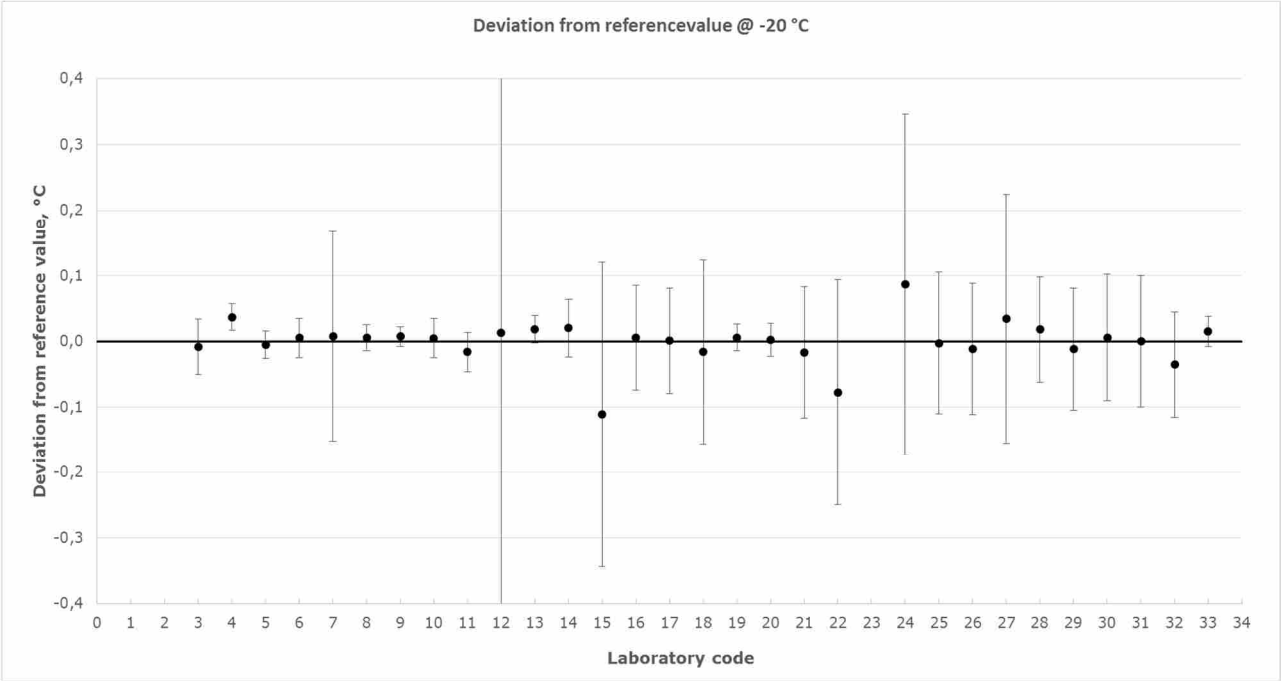
Table 20: Errors reported by the participants for the 9 mm sensor in °C.

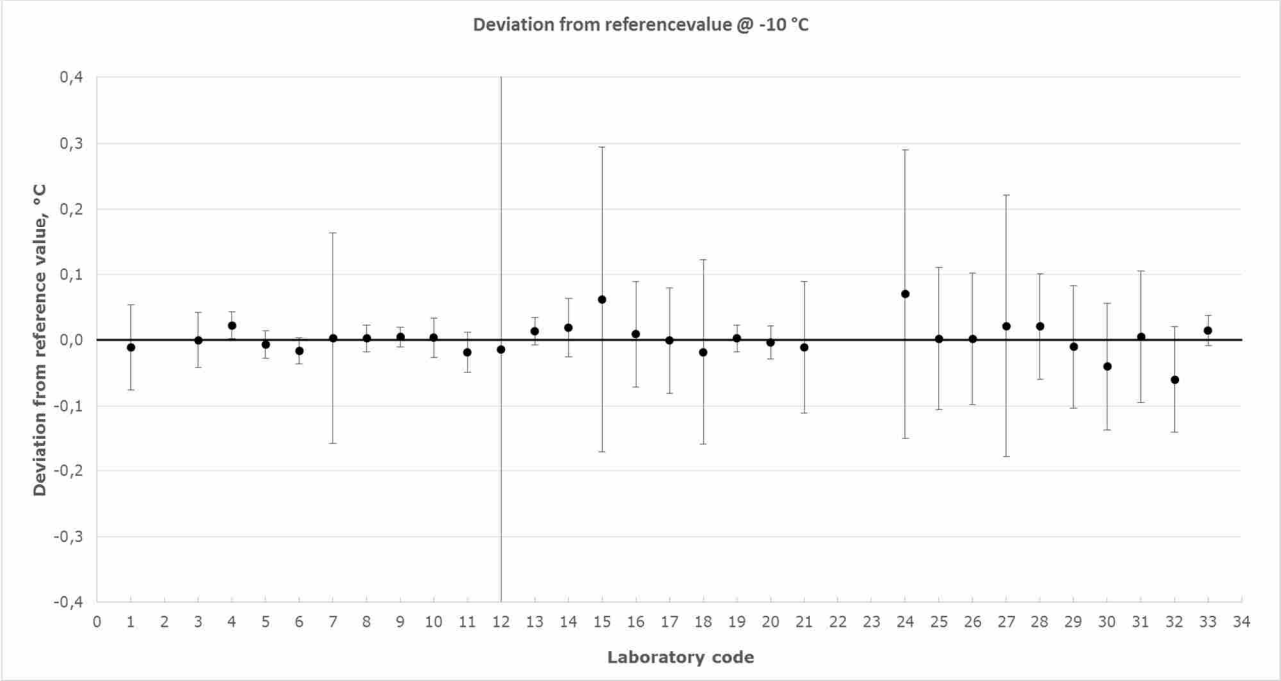
Lab code	Nominal temperature						
	-40 °C	-20 °C	-10 °C	0 °C	75 °C	150 °C	230 °C
1			0.065	0.065	0.065	0.065	0.084
2					0.19	0.23	0.27
3		0.042	0.042	0.042	0.052	0.062	
4	0.040	0.030	0.030	0.030	0.050	0.050	0.060
5	0.021	0.021	0.021	0.010	0.021	0.021	0.031
6		0.030	0.020	0.020	0.020	0.020	0.020
7		0.16	0.16	0.16	0.16		
8	0.020	0.020	0.020	0.020	0.020	0.020	
9	0.020	0.020	0.020	0.020	0.020	0.020	0.020
10	0.050	0.040	0.040	0.030	0.040	0.050	0.050
11	0.030	0.030	0.030	0.030	0.030	0.030	0.031
12	0.50	0.50	0.50	0.50	0.50	0.60	0.60
13	0.034	0.033	0.036	0.036	0.035	0.039	
14	0.044	0.044	0.044	0.044	0.044	0.044	0.044
15		0.23	0.23	0.23	0.23	0.23	
16	0.080	0.080	0.080	0.080	0.080	0.080	0.36
17		0.080	0.080	0.080	0.080	0.11	0.17
18		0.14	0.14	0.14	0.60	0.60	0.60
19	0.030	0.030	0.030	0.030	0.030	0.030	0.030
20	0.045	0.025	0.025	0.025	0.020	0.026	0.063
21		0.10	0.10	0.10	0.10	0.60	
22		0.17		0.17	0.18	0.35	0.39
23							
24	0.33	0.26	0.22	0.16	0.26	0.28	0.20
25	0.11	0.11	0.11	0.10	0.10	0.10	0.10
26	0.10	0.10	0.10	0.10	0.10	0.20	0.30
27	0.19	0.17	0.18	0.17	0.14	0.18	
28	0.070	0.070	0.070	0.070	0.070	0.070	
29	0.093	0.093	0.093	0.093	0.093	0.093	0.093
30	0.096	0.096	0.096	0.025	0.10	0.10	0.10
31		0.10	0.10	0.10	0.10	0.10	
32	0.080	0.080	0.080	0.010	0.030	0.050	0.080
33	0.028	0.025	0.024	0.024	0.026	0.037	

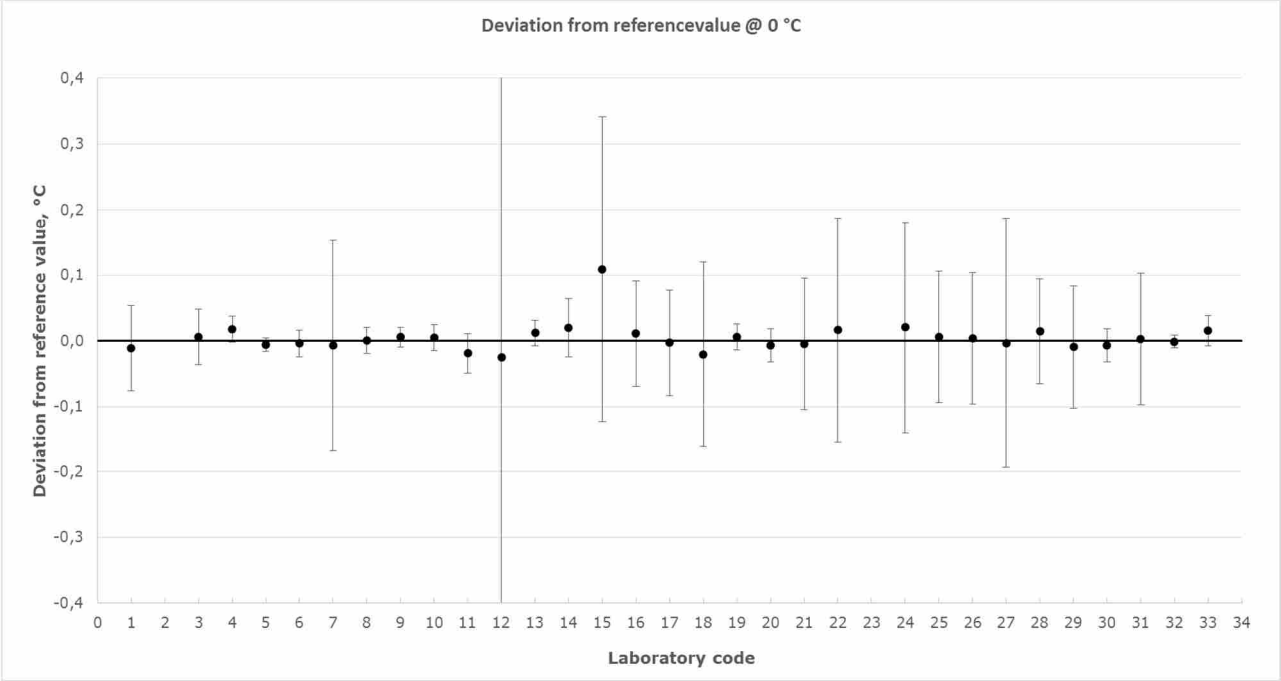
Table 21: Uncertainty reported by the participants for the 9 mm sensor in °C.

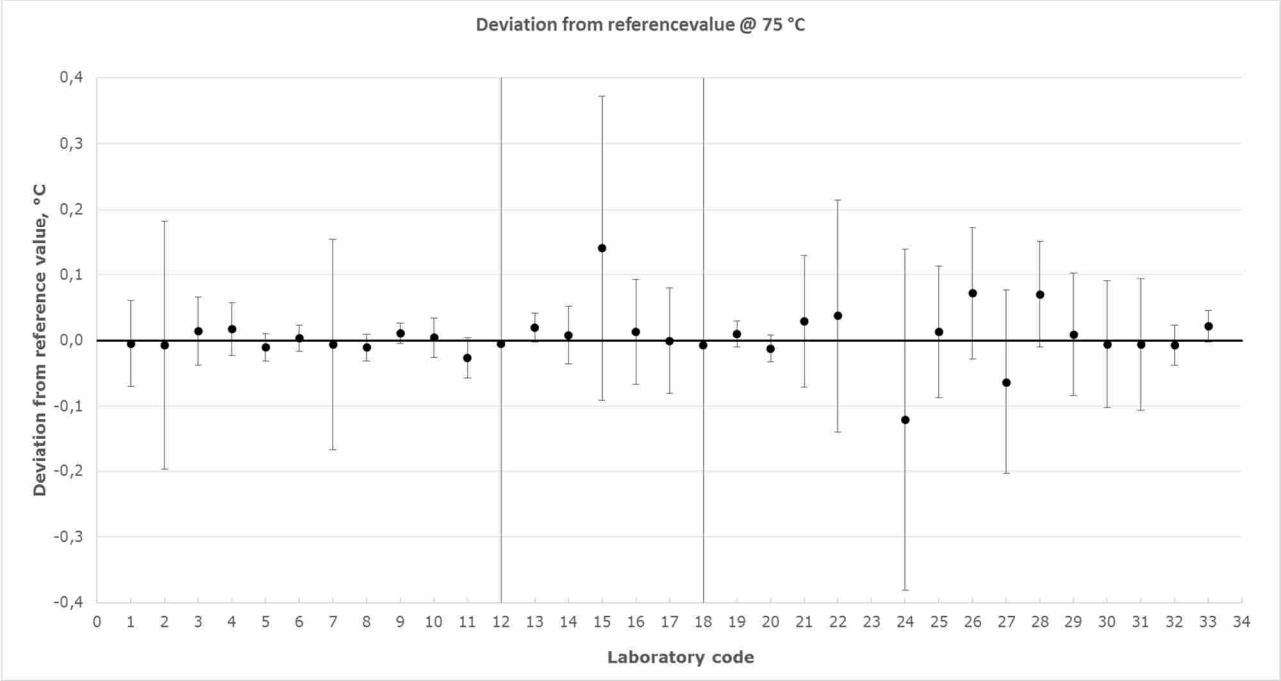
Appendix 4: Results – Graphs for 4 mm sensor

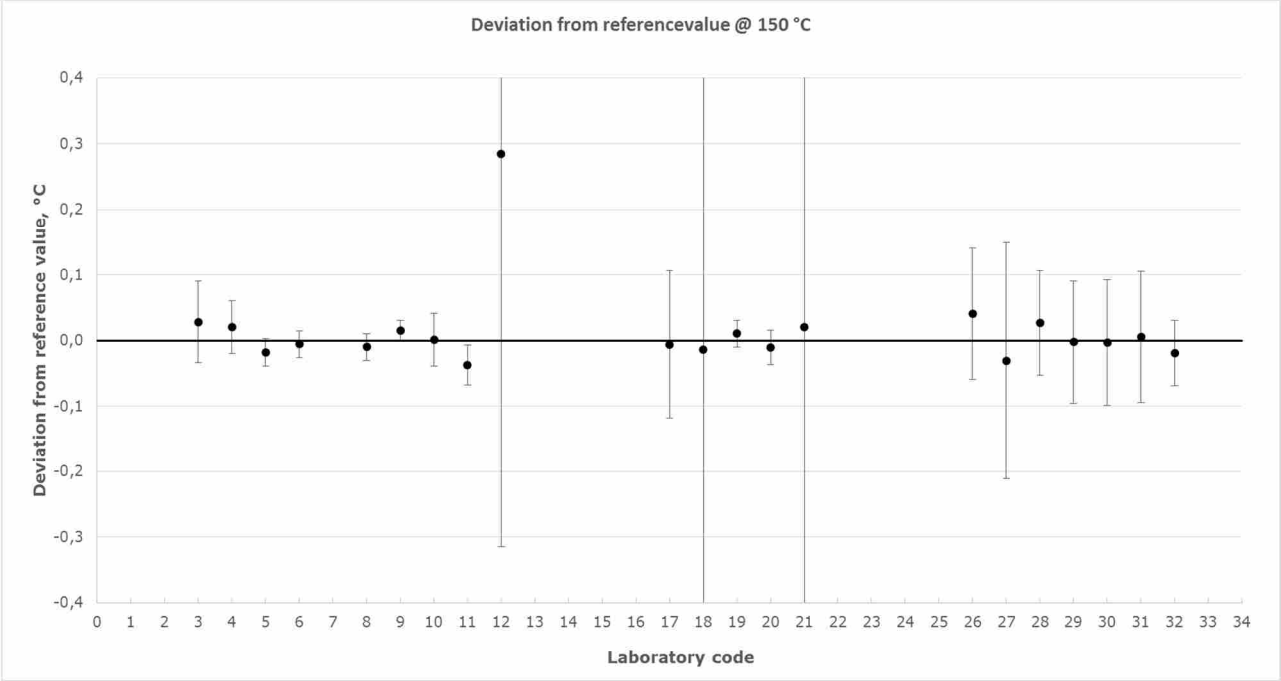


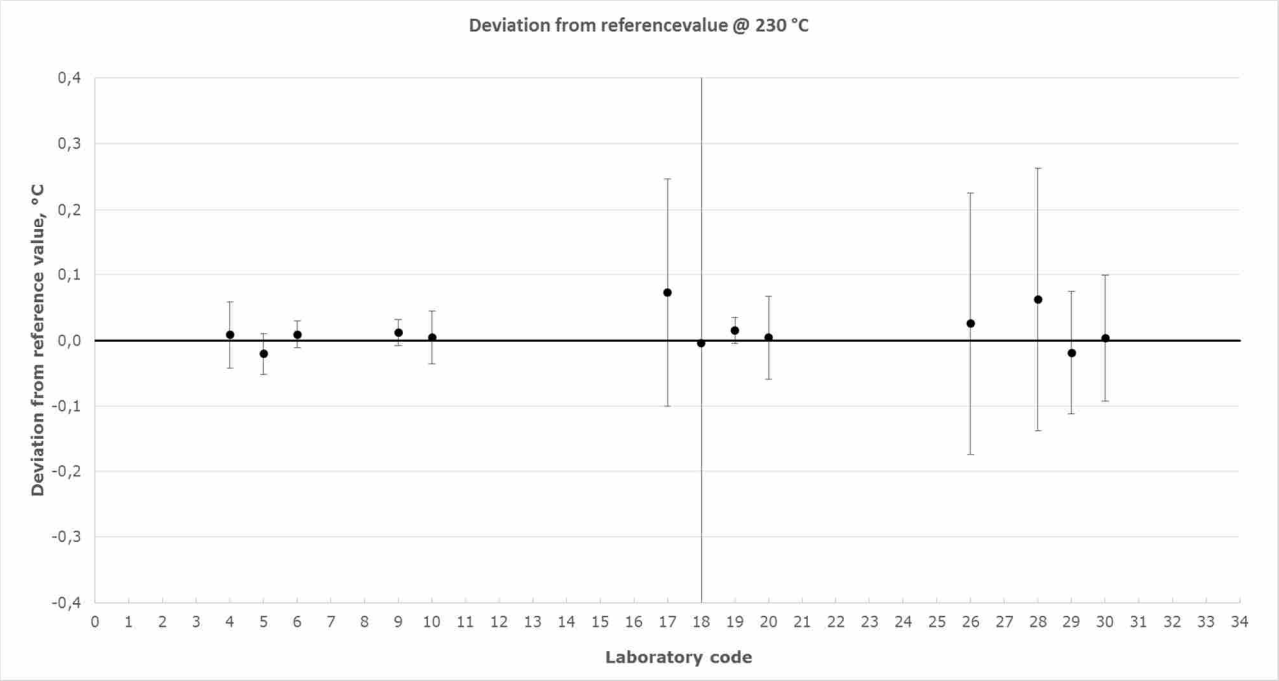



Deviation from referencevalue @ -10 °C
Deviation from reference value, °C
0,4
0,3
0,2
0,1
0,0
-0,1
-0,2
-0,3
-0,4
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34
Laboratory code

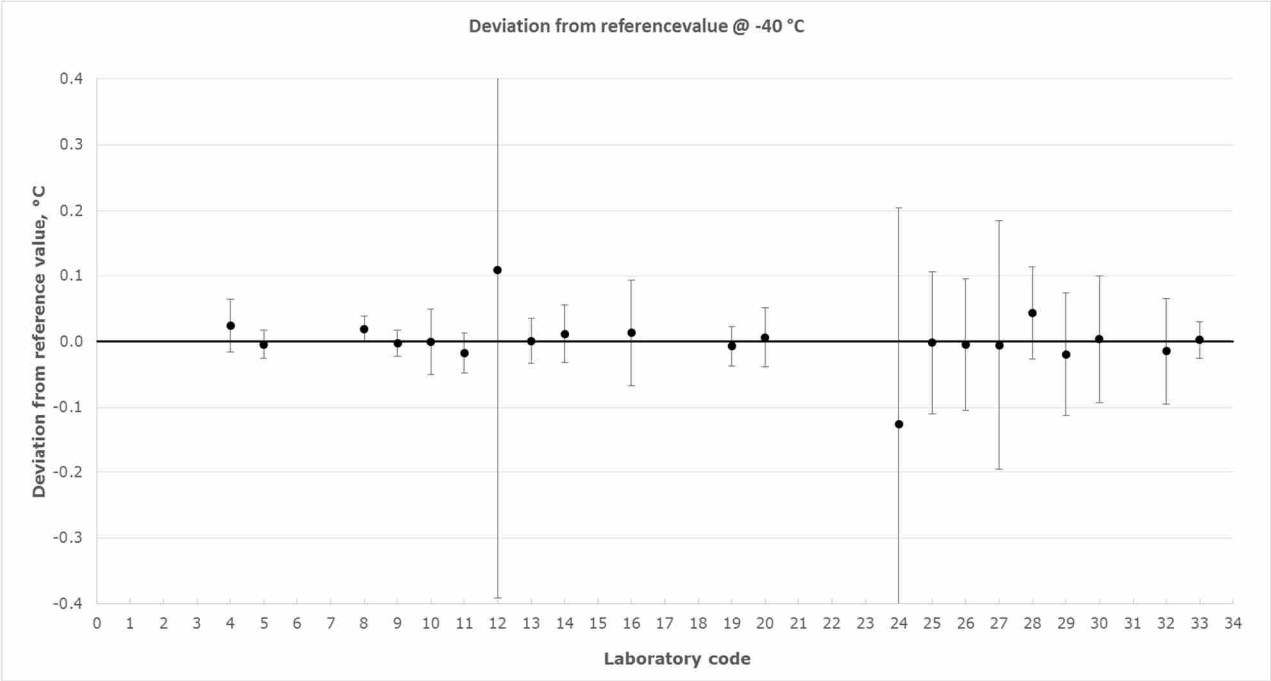

Deviation from referencevalue @ 0 °C
Deviation from reference value, °C
0,4
0,3
0,2
0,1
0,0
-0,1
-0,2
-0,3
-0,4
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34
Laboratory code

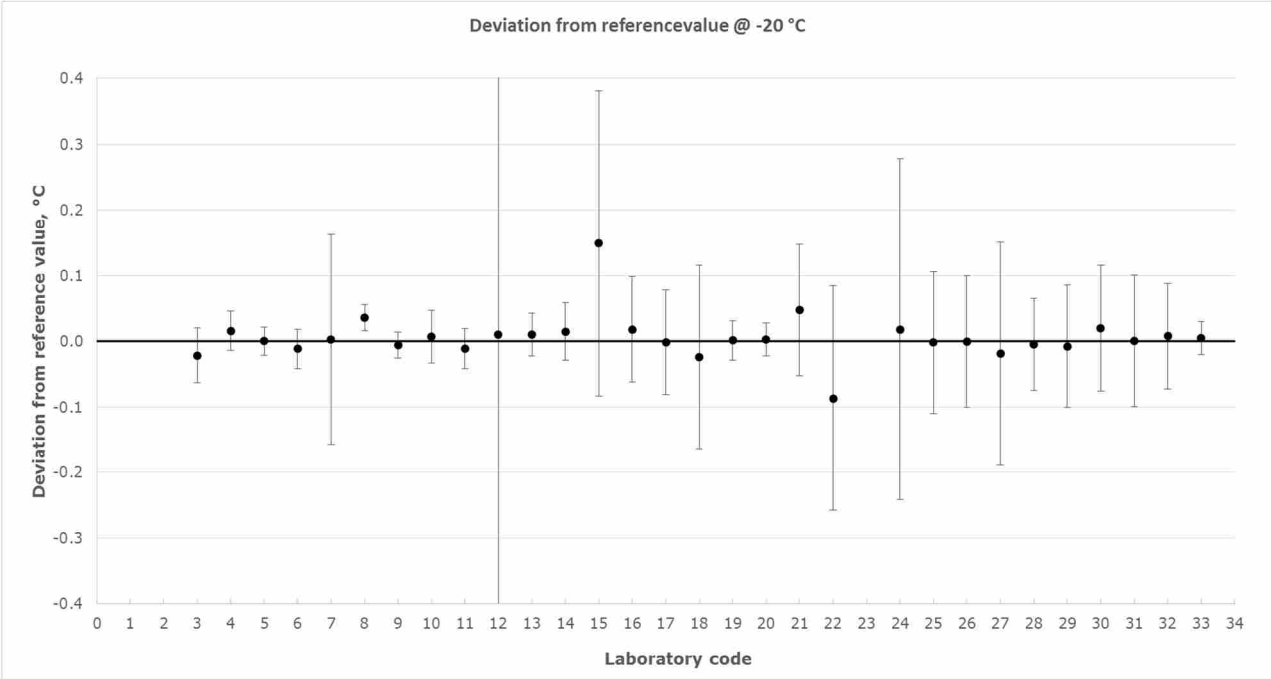

Deviation from referencevalue @ 75 °C
Deviation from reference value, °C
0,4
0,3
0,2
0,1
0,0
-0,1
-0,2
-0,3
-0,4
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34
Laboratory code

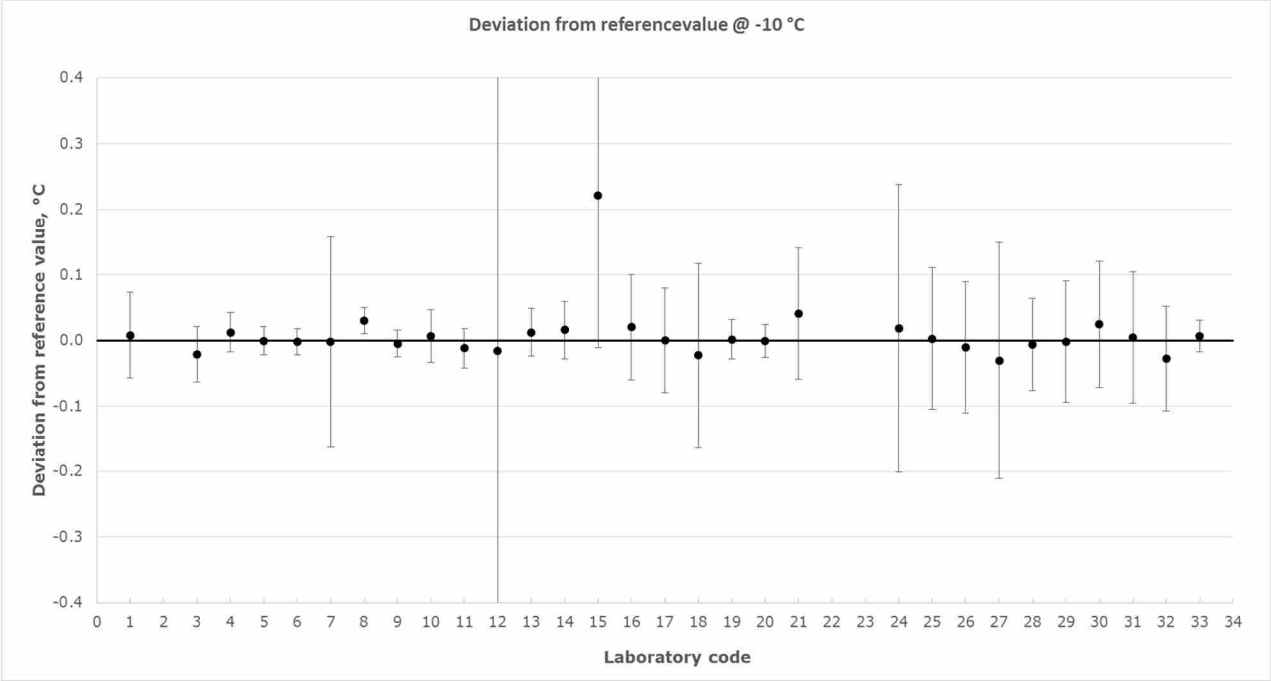

Deviation from referencevalue @ 150 °C
Deviation from reference value, °C
0,4
0,3
0,2
0,1
0,0
-0,1
-0,2
-0,3
-0,4
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34
Laboratory code

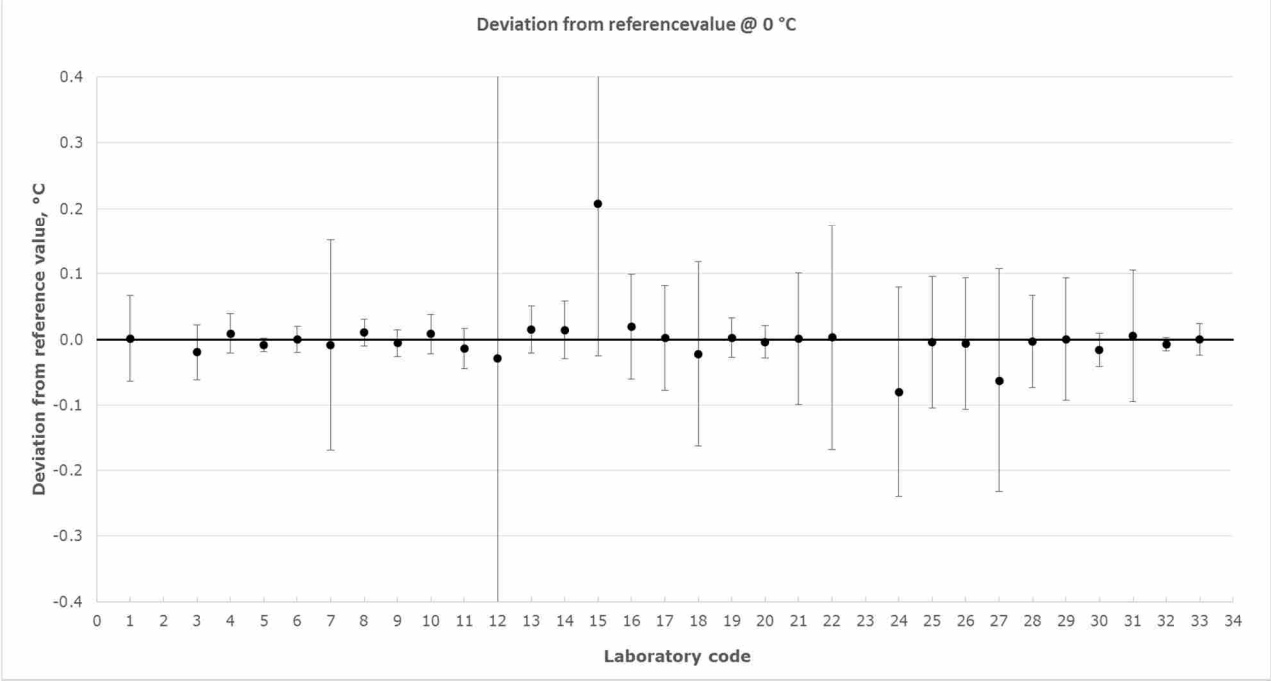

Deviation from referencevalue @ 230 °C
Deviation from reference value, °C
0,4
0,3
0,2
0,1
0,0
-0,1
-0,2
-0,3
-0,4
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34
Laboratory code

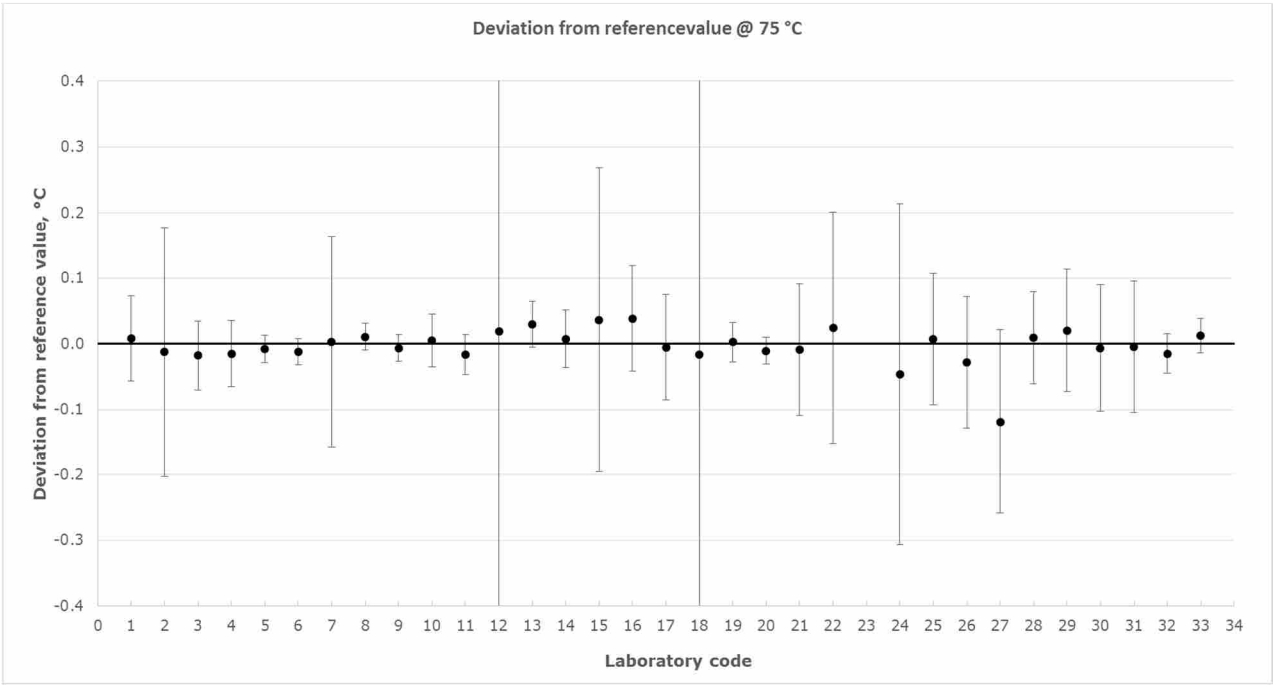
Appendix 5: Results – Graphs for 9 mm sensor

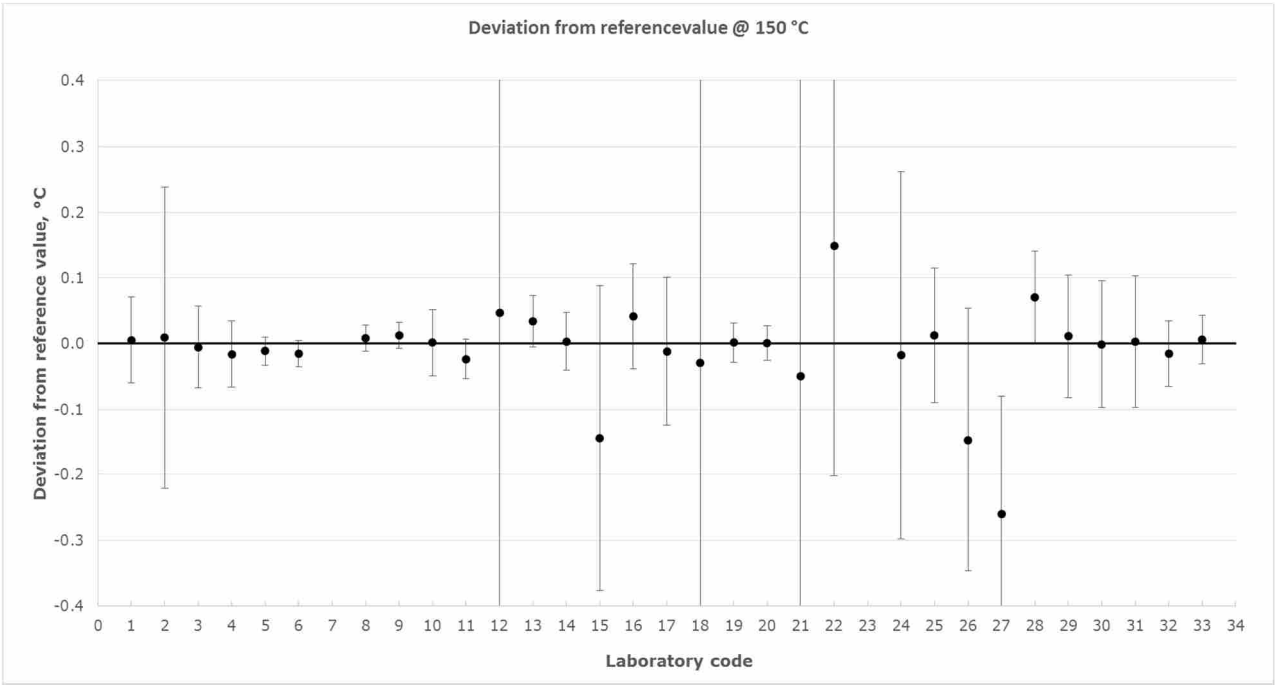


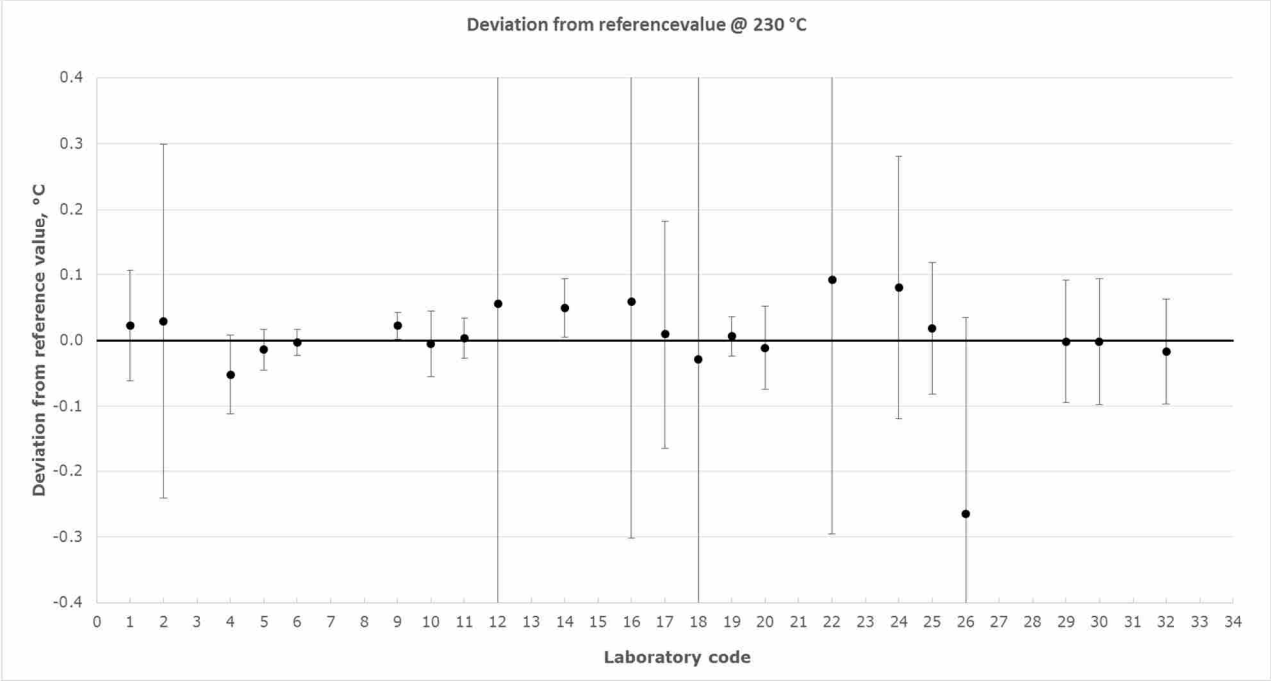



Deviation from referencevalue @ -10 °C
Deviation from reference value, °C
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34
Laboratory code


Deviation from referencevalue @ 0 °C
Deviation from reference value, °C
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34
Laboratory code


Deviation from referencevalue @ 75 °C
Deviation from reference value, °C
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34
Laboratory code


Deviation from referencevalue @ 150 °C
Deviation from reference value, °C
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34
Laboratory code


Deviation from referencevalue @ 230 °C
Deviation from reference value, °C
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34
Laboratory code